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REPORT

Subjective effects of band-limiting the colour-difference signals in PAL television System I

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THE BRITISH BROADCASTING CORPORATION August 1976

BBC RD 1976/19
UDC 621.397.132.125:
621.391.837

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Summary

This report describes an initial study of the subjective effects of band-limiting colour-difference signals in PAL television System I. It provides a basis for possible future work on minimising the sampling frequency required in the digital encoding of colour-difference signals. It was estimated from results that the optimum U', V' transmission filter characteristic, which may be used prior to digital encoding of the U', V' signals, is likely to be one with an upper cut-off frequency of about 2 MHz and a −3 dB frequency of about 1·2 MHz, with a non-oscillatory impulse response.

Issued under the authority of

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August 1976
(EL-119)

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1. Introduction

An earlier BBC Research Department Report[1] has outlined separate-component coding for the digital transmission of colour television signals, and one of its conclusions was that further investigations would be needed in order to provide estimates of the sampling frequencies required for coding luminance and colour-difference signals.

These investigations were later begun with a study of the literature regarding the gamma-corrected colour-difference signals*, U' and V', in PAL television System I;[2] this revealed that the U', V' band-limiting characteristic was not sufficiently well defined for the purpose of choosing a sampling frequency for efficient digital encoding. A study was therefore made of the subjective effects introduced by using transmission filters to band-limit the colour-difference signals and then processing them with a PAL System I codec. The band-limiting introduced by the transmission filter is, of course, additional to that of the PAL codec itself. The work described was undertaken with the aim of defining the problems associated with choosing an optimum U', V' band-limiting characteristic (transmission filter). When this optimum transmission filter characteristic is introduced before a PAL codec there should be no resultant increase in subjective impairment on pictures reproduced from the decoded PAL signals.

2. Preliminary experiments

2.1. Selection of experimental filter characteristics

It was apparent that the first step in deciding the optimum U', V' transmission filter characteristic would be to study the subjective impairments produced by a number of U', V' filters. Informal viewing tests confirmed that sharp cut U', V' filters could produce "ringing" at vertical transitions between coloured areas. Small amounts of ringing (approximately 2% peak-to-peak) were visible, particularly when the test picture was colour bars. These tests also confirmed that owing to their non-oscillatory impulse responses, raised-cosine U', V' filters do not produce ringing, but too narrow a bandwidth can cause transition broadening. It was decided that filter characteristics for formal subjective tests would be chosen with the intention of displaying degrees of subjective impairment ranging from "broadening of colour transitions with no ringing" to "ringing at colour transitions with no broadening". These subjective tests would necessarily include visually similar impairments due to normal analogue PAL coding and decoding. This second consideration meant that at least one of the U', V' transmission filter characteristics should not substantially modify the overall response of the U', V' channel in the PAL codec.

The overall amplitude-frequency characteristic of the U', V' chrominance channels, averaged together, of a PAL codec was measured, and the graph is given in Fig. 1; a more detailed description of this work is included in Appendix 1.

Four transmission filter characteristics were subsequently chosen to cover the proposed range of picture impairments. Group-delay correction was included with one of the filters and optionally with two more, so that its subjective desirability could be assessed; its inclusion was expected to reduce the visibility of ringing effects. Three filters, nos. 1, 2 and 3, were of the second-order elliptic type, with −3 dB frequencies of 1·5 MHz, 1·1 MHz and 700 kHz, respectively, while filter no. 4 was a raised-cosine filter with a −3 dB frequency of 400 kHz. The amplitude-frequency characteristic of the raised-cosine filter is shown in Fig. 2. As the three other filters are of

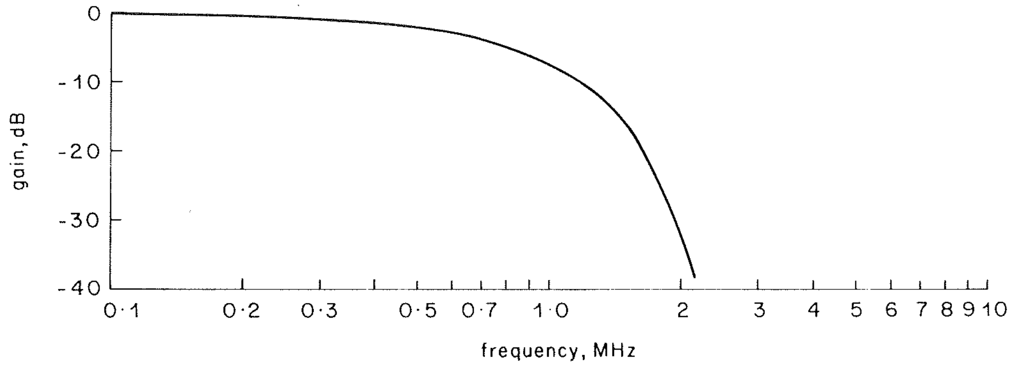

Fig. 1 - Measured amplitude-frequency characteristic of the U', V' chrominance channels, averaged together, of a PAL codec.

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* U' and V' are proportional to B'-Y' and R'-Y', respectively, where B', R', and Y' are the gamma-corrected blue, red and luminance signals, respectively; G' will denote the gamma-corrected green signal.

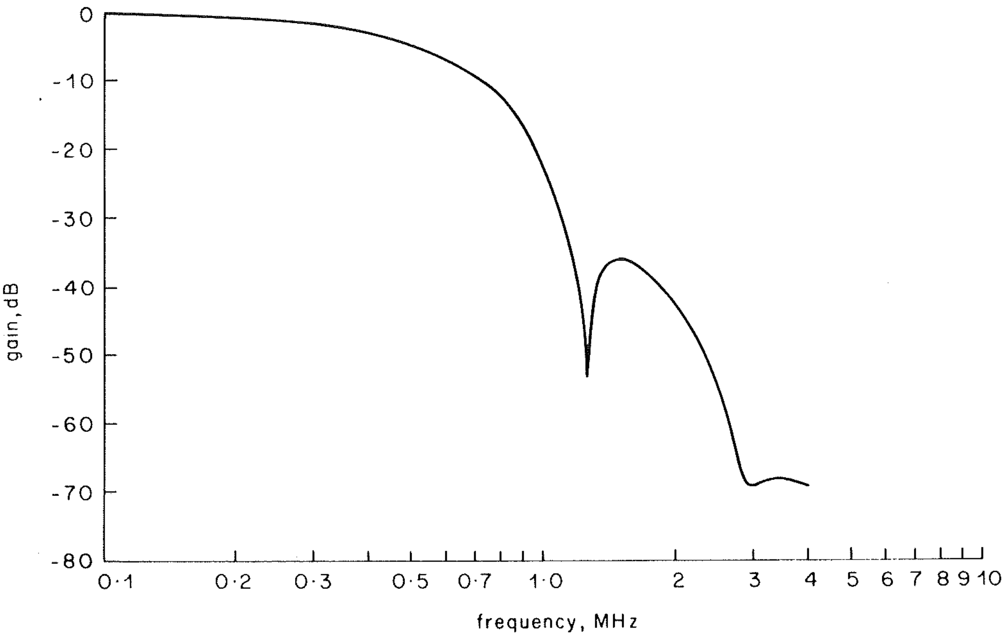


Fig. 2 - Amplitude-frequency characteristic of filter no. 4

the same type, only the 1·5 MHz filter characteristic is given, and this appears in Fig. 3. Circuit details, together with details of the group-delay corrector performance, are given in Appendix 2.

2.2. Apparatus

The apparatus used in the subjective tests is illustrated in Fig. 4: buffering and gain amplifiers in the Y', U', V' channels are omitted for clarity. Gamma-corrected primary colour signals R'_0, G'_0, B'_0 are obtained from a picture source not shown on the diagram (flying-spot slide-scanner, or colour-bar generator). The colour matrix combines these source signals and produces colour-difference signals U'_0, V'_0 and a luminance signal Y'_0. A variable delay (t) was inserted in the Y channel to match the delays introduced by the experimental U', V' low-pass transmission filters to within 50 ns.[3] Standard PAL codecs are designed to work from $R'G'B'$ inputs so an inverse matrix is employed to reform R'_1, G'_1, B'_1 signals from the Y'_0, U'_0, V'_0 signals. The output of the PAL codec is then displayed on a colour-picture monitor.

3. Subjective test procedure

Groups of nine or ten experienced observers took part

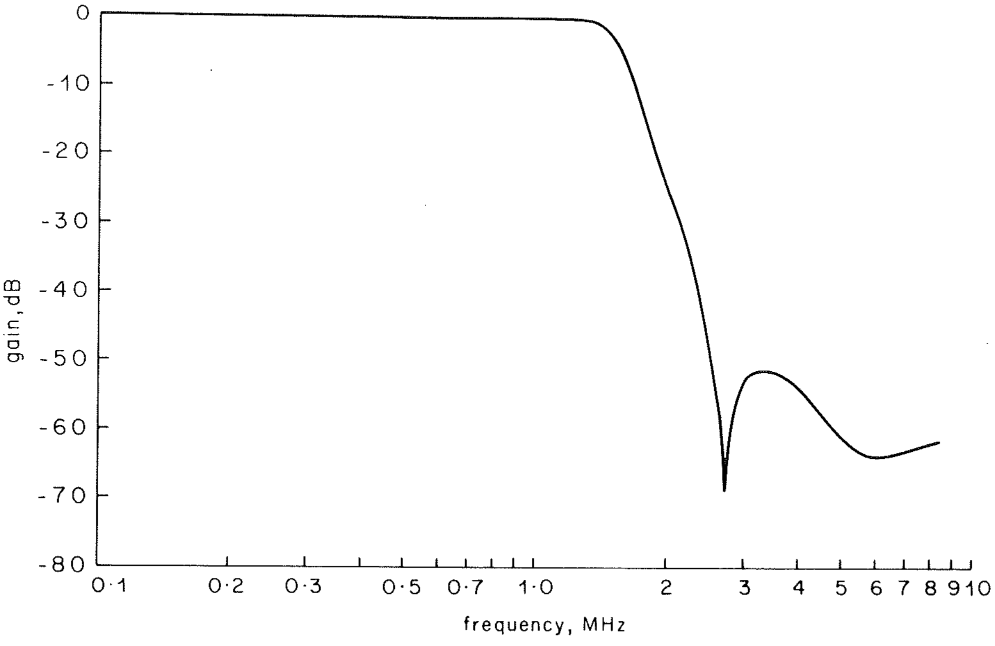


Fig. 3 - Amplitude-frequency characteristic of filter no. 1

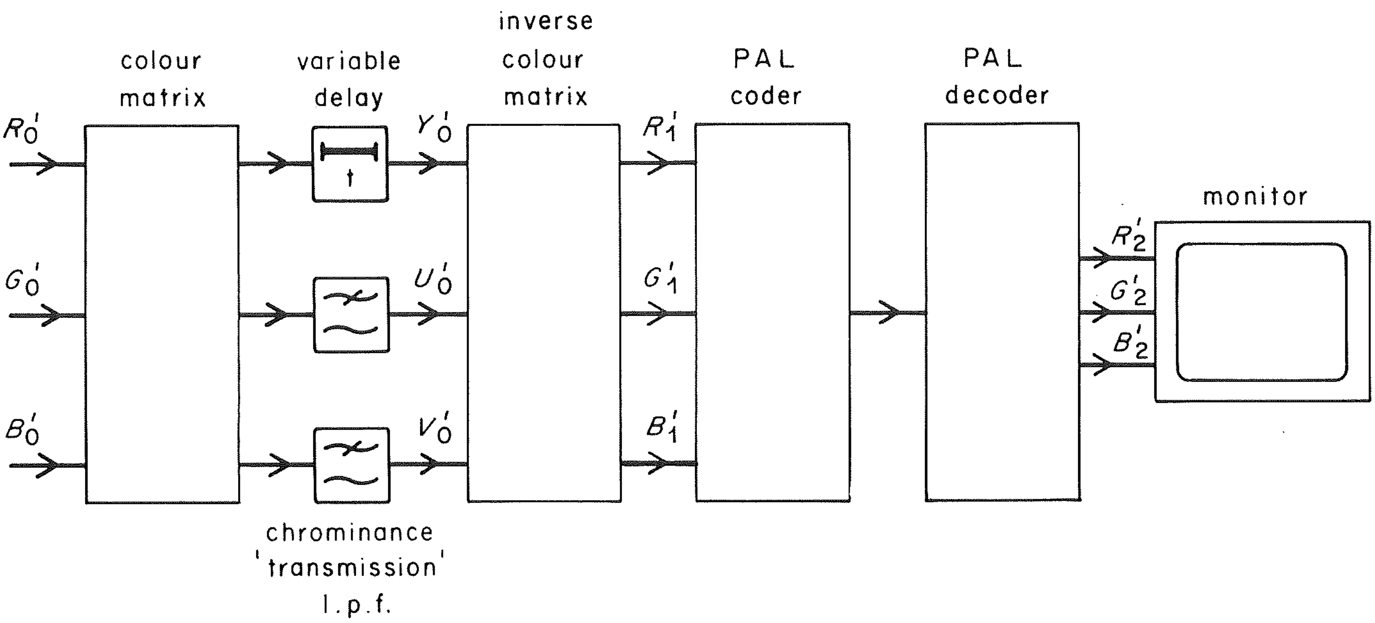


Fig. 4 - Apparatus used in the subjective tests

in subjective tests where they were asked to grade the impairment caused by the introduction of different U', V' transmission filters. Before each test picture, a reference condition was shown in which the transmission filters were by-passed. This step was taken to assist the observers in ignoring possible residual picture impairment, due to PAL coding and decoding, on subjective assessments.

The six-point impairment scale, shown in Table 1, was used in the tests*. Four test pictures were employed, and for each picture the U', V' transmission filters and the by-pass condition were presented in an order which was random and was changed for each picture. The four pictures were:

1. 100% saturated vertical colour bars.
2. "Graticule" slide, with only the red channel (R'_0) on (see Fig. 5).
3. "Girl with scarf" slide.
4. "Girl with hat" slide.

Initially, CCIR viewing conditions, described in Table 2(a) were used, and observers sat between four and six picture heights from the picture monitor. With the CCIR viewing conditions, observers complained that pictures were desaturated and lacked contrast and consequently tests were repeated with the viewing conditions described in Table 2(b).

The tests were carried out with viewing condition (a) for all four pictures; they were repeated for pictures 1 and 3 with viewing condition (b). Observers were asked to state (in addition to the impairment grade) whether the picture impairment was due to ringing, broadening, or hue changes or a combination of these.

4. Results

Mean subjective impairment grades obtained in the tests, and their standard errors are presented in Table 3. An interesting result was that virtually all of the impairment grades were materially unaffected by changing the viewing conditions from (a) to (b). As expected, the wide bandwidth filters caused least impairment and group-delay correction of filters 2 and 3 reduced impairment by at least 0·4 of a grade. Although the raised-cosine filter has a similar bandwidth to the 700 kHz sharp-cut filter (they are asymptotic at high frequencies), its associated impairment was significantly less, and it compares favourably with the 1·1 MHz filter with group-delay correction.

TABLE 1

Impairment scale

1. Not perceptible
2. Just perceptible
3. Definitely perceptible but not disturbing
4. Somewhat objectionable
5. Definitely objectionable
6. Unusable

---

* If the impairment on this scale is A_6, the impairment on the CCIR five-point impairment scale is, as a first approximation, given by $A_5 = 5{\cdot}8 - 0{\cdot}8\ A_6$; see CCIR Rec. 500 (1974).

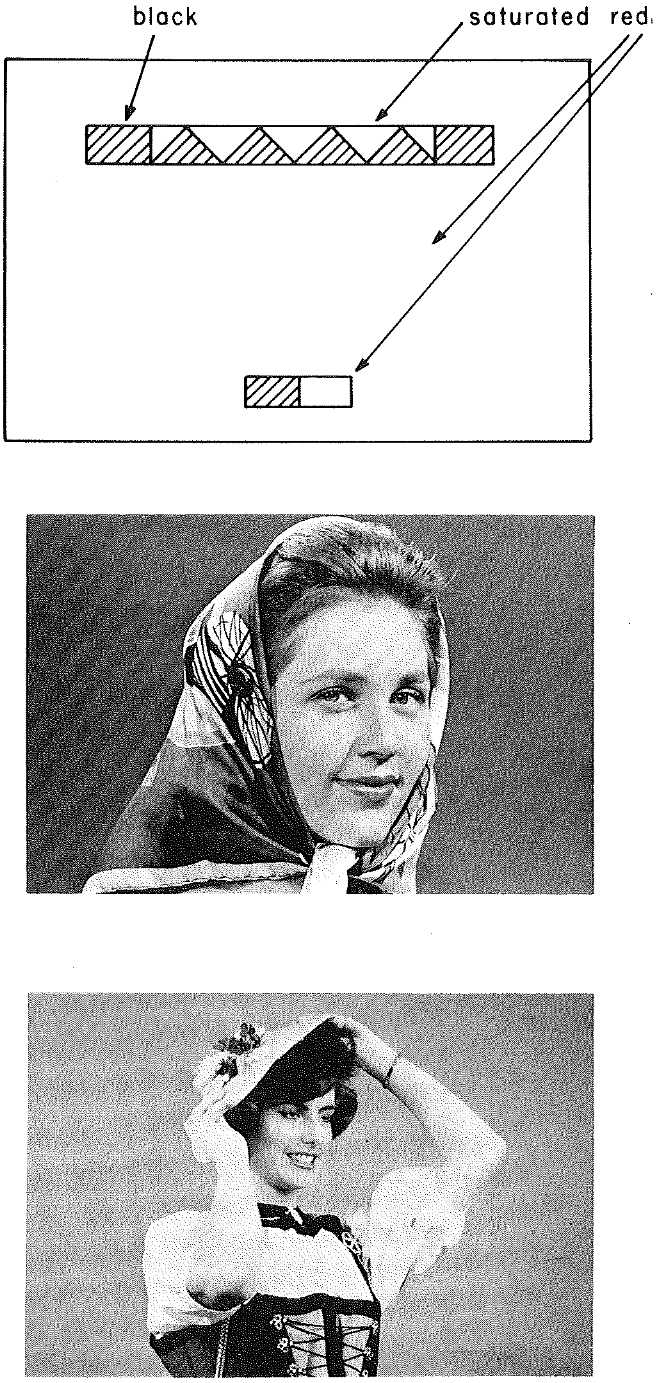


Fig. 5 - Picture nos. 2, 3 and 4

It emerges from an analysis of the results that pictures 3 and 4 ("Girl with scarf" and "girl with hat") mask the effects of the filters, resulting in a difference of as many as four grades in the impairment of both picture 3 and 4, relative to that of the somewhat artificial test pictures (1 and 2). If all broadcast pictures were similar to pictures 3 and 4, then all the filters, except the 700 kHz sharp-cut, would probably be suitable for broadcast purposes as they all introduce not more than about half a grade of impairment. But since pictures similar to test pictures 1 and 2 (containing large transitions between saturated colours) might be used on some programme material, the worst-case picture encountered, namely 100% colour bars, should be considered as relevant. On colour bars, all the filters introduce an unacceptable degree of impairment for broadcast purposes. The group-delay corrected 1·5 MHz sharp-cut filter, which causes least damage, introduces just visible ringing which is most noticeable on the green to magenta transition of 100% saturated vertical colour bars.

It was concluded from answers to questions presented in the subjective tests that if any hue changes were introduced by the U', V' transmission filters they were certainly not visible.

For instrumental convenience it is at present the practice to obtain a gamma-corrected luminance signal Y' by making an arithmetic sum of gamma-corrected colour-separation signals instead of by gamma-correcting an arithmetic sum of colour-separation signals. This causes some high-frequency brightness information to be carried in the U', V' colour-difference signals. When these colour difference signals are band-limited, some of the high-frequency brightness information is lost, and the sharpness of transitions between coloured areas of different brightness is therefore reduced.

If ringing occurs in the U', V' chrominance channels of a PAL codec this will, by the mechanism described above, produce a ringing in the displayed brightness. The visibility of ringing at transitions between coloured areas is also affected by chrominance to luminance crosstalk generated within the PAL codec. This is a result of high-frequency chrominance energy not being completely removed from the luminance channel by the notch filter in the decoder. Rectification of this modulated signal by the non-linearity of the display device causes the crosstalk to appear as crawling dots modulating the brightness at the transition.

TABLE 2

Viewing conditions

(a) CCIR (Rec. 500) viewing condition

Peak white luminance	=	68 cd/m^2
Screen luminance with zero beam current	=	0.68 cd/m^2
Screen luminance with no black level and no ambient light	=	0.68 cd/m^2

(b) Alternative viewing condition also used in tests

Peak white	68 cd/m^2 (as for Condition (a))
Ambient light off the screen with zero beam current	0.15 cd/m^2
Screen luminance with no video or ambient light	0.0086 cd/m^2

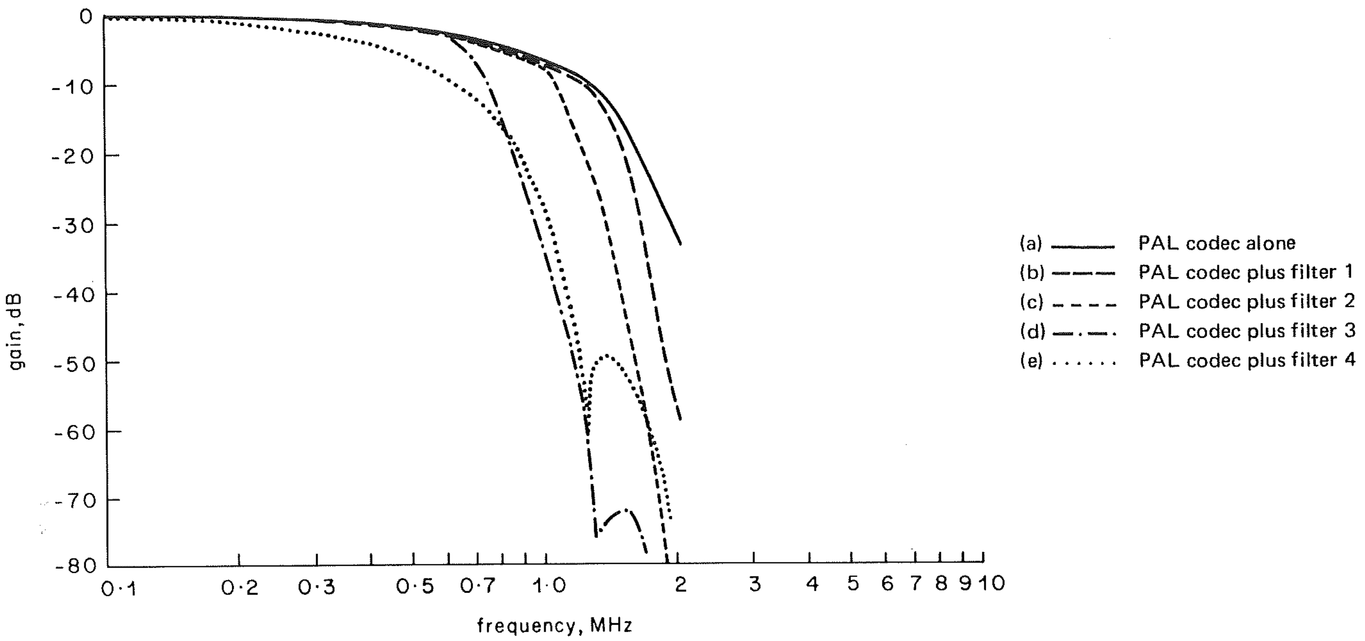


Fig. 6 - Amplitude-frequency characteristics of PAL codec in tandem with experimental U', V' transmission filters:

TABLE 3

Results of the Subjective Tests

MEAN IMPAIRMENT GRADE (STANDARD ERROR OF THE MEAN GIVEN IN BRACKETS)

	Viewing condition (a)				Viewing condition (b)	
Picture	1	2	3	4	1	3
Transmission Filters						
1. 1·5 MHz with GDC	2·4 (0·16)	2·0 (0·15)	1·5 (0·26)	1·2 (0·15)	2·1 (0·31)	1·2 (0·13)
2. 1·1 MHz with GDC	3·7 (0·15)	3·2 (0·21)	1·1 (0·10)	1·0 (0·00)	3·9 (0·26)	1·1 (0·10)
2. 1·1 MHz no GDC	4·5 (0·17)	3·8 (0·24)	1·2 (0·13)	1·1 (0·11)	4·5 (0·17)	1·0 (0·0)
3. 700 kHz with GDC	4·6 (0·16)	4·3 (0·36)	1·4 (0·16)	1·9 (0·26)	4·6 (0·26)	1·3 (0·15)
3. 700 kHz no GDC	5·1 (0·20)	4·7 (0·23)	–	1·2 (0·15)	5·5 (0·15)	1·4 (0·31)
4. 400 kHz raised cosine	2·8 (0·29)	3·8 (0·36)	1·2 (0·20)	1·6 (0·24)	3·5 (0·27)	1·0 (0·00)
Bypass	1·4 (0·18)	1·1 (0·10)	1·0 (0·00)	1·0 (0·00)	1·6 (0·22)	1·0 (0·00)

The −3 dB frequencies of the filters are quoted
GDC = Group delay correction

A first analysis, based on a theoretical model and some simple subjective measurements, tended to confirm that the above factors are responsible for visible impairment resulting from ringing in the chrominance channel, but it is not clear which is the dominant factor.

As far as the subjective impairment of chrominance transition broadening due to U', V' transmission filters is concerned, the raised cosine filter of 400 kHz bandwidth which introduced no ringing, caused unacceptable broadening of transitions on colour bars; filters 1, 2, and 3 produced no noticeable broadening.

The choice of an optimum characteristic for the U', V' transmission filters would require further subjective investigations, but a possibly optimum characteristic can be deduced by first plotting the overall amplitude-frequency characteristics of the transmission filters connected in tandem with the PAL codec as in Fig. 4. This is presented in Fig. 6. By comparing the results in Table 3 with the plots in Fig. 6 it can be seen that filters 1, 2, 3, which did not produce noticeable transition broadening, also did not significantly modify the PAL codec response at signal frequencies below 600 kHz whereas the 400 kHz raised cosine filter which produced significant broadening did modify the overall response below 600 kHz. The optimum filter is therefore most likely to be a raised-cosine filter (see Section 2.1.) with a −3 dB frequency of 1·2 MHz as this should not introduce additional broadening or ringing. In order to lower the cut-off frequency of this transmission filter a sharp-cut filter could be used in tandem, but its −3 dB frequency would have to be carefully chosen in order that the impulse response of the transmission filter should be substantially non-oscillatory. A suitable sharp-cut filter would probably have a cut-off frequency of at least 2 MHz.

5. Conclusions

Subjective tests have shown that band-limiting of the colour-difference signals can produce visible changes at transitions between coloured areas of a test picture, and that these changes are seen either as broadening of the transition area, or as oscillatory changes ('ringing') in brightness following the transition edge, or both. It was also found that band-limiting does not cause any noticeable hue change.

The results suggest that a fairly narrow-bandwidth, acceptable characteristic may be obtained with a raised-cosine filter, −3 dB at 1·2 MHz, in tandem with a sharp-cut filter (preferably group-delay corrected) with a cut-off frequency of at least 2 MHz. The choice of the cut-off frequency for the sharp-cut filter must be consistent with keeping the impulse response of the colour-difference channel non-oscillatory and with ensuring that, if the colour-difference signals are sampled after being band-limited, the attenuation of unwanted alias components is sufficient to enable an advantageously low sampling frequency to be used.

This U', V' transmission-filter characteristic has a wider bandwidth than the U', V' channels in a PAL codec. Therefore, in a transmission path comprising several cascaded digital Y', U', V', links and analogue PAL links, the cascaded PAL codecs will limit the overall chrominance-bandwidth of the path. This implies that bandwidth of the U', V' transmission-filters in an individual digital Y', U', V' codec need not be widened to allow for the several digital Y', U', V' codecs in the path.

The study provides a basis on which to plan future work to determine an optimum colour-difference signal band-limiting characteristic, with a view to economic digital encoding of the colour-difference signals in PAL television System I.

The results in this report apply when using a good quality decoder. In general the optimum transmission filter will depend on the bandwidth of the PAL codec. Future work might explore the possible advantage of a transmission filter which partially corrects for the PAL codec response.

6. References

1. MOORE, T.A. 1974. Digital Video: number of bits per sample required for reference coding of luminance and colour-difference signals. BBC Research Department Report No. 1974/42.

2. Specification of television standards for 625-line System I transmissions. January 1971. BBC and IBA.

3. DEVEREUX, V.G. *and* WILKINSON, G.C. 1973. Visibility of chrominance/luminance delay inequality in System I (625-line PAL) video signals. BBC Research Department Report No. 1973/35.

4. LENT, S.J. *and* REED, C.R.G. 1974. Reduction of cross-colour effects in PAL (System I) colour television by the use of low-pass and notch filters: subjective tests. BBC Research Department Report No. 1974/25.

7. APPENDIX 1

PAL Codec Bandwidth Measurements

As a starting point in the design of the U', V' transmission filters preceding the PAL codec, the frequency response of the chrominance channels of the PAL coder and PAL decoder were measured using a spectrum analyser and signal-generator which tracked the sweep of the analyser. (Fig. 7 illustrates the various filters incorporated in the coder and decoder.) The signal generator was followed by a blanking unit (to enable the PAL coder to function correctly) and they were arranged to provide a sinusoid excursing between black level and peak white (0·7 V). The decoder used had a relatively wide chrominance band-pass filter, as the effects of transmission filter ringing are then more visible.

The spectra are characterised by a line structure with a uniform spacing of 15 kHz. The envelope of the line structure is the spectrum of individual lines. The scanning rate of the tracking sinusoid was arranged such that the measured amplitude was averaged over many lines (always more than 20). The results are recorded in Table 4 and Fig. 1. The chrominance band-pass filter characteristic in the decoder, combined with the subsequent U' or V' low-pass filters is given in Fig. 8 (from Fig. 3 of Ref. 4 for

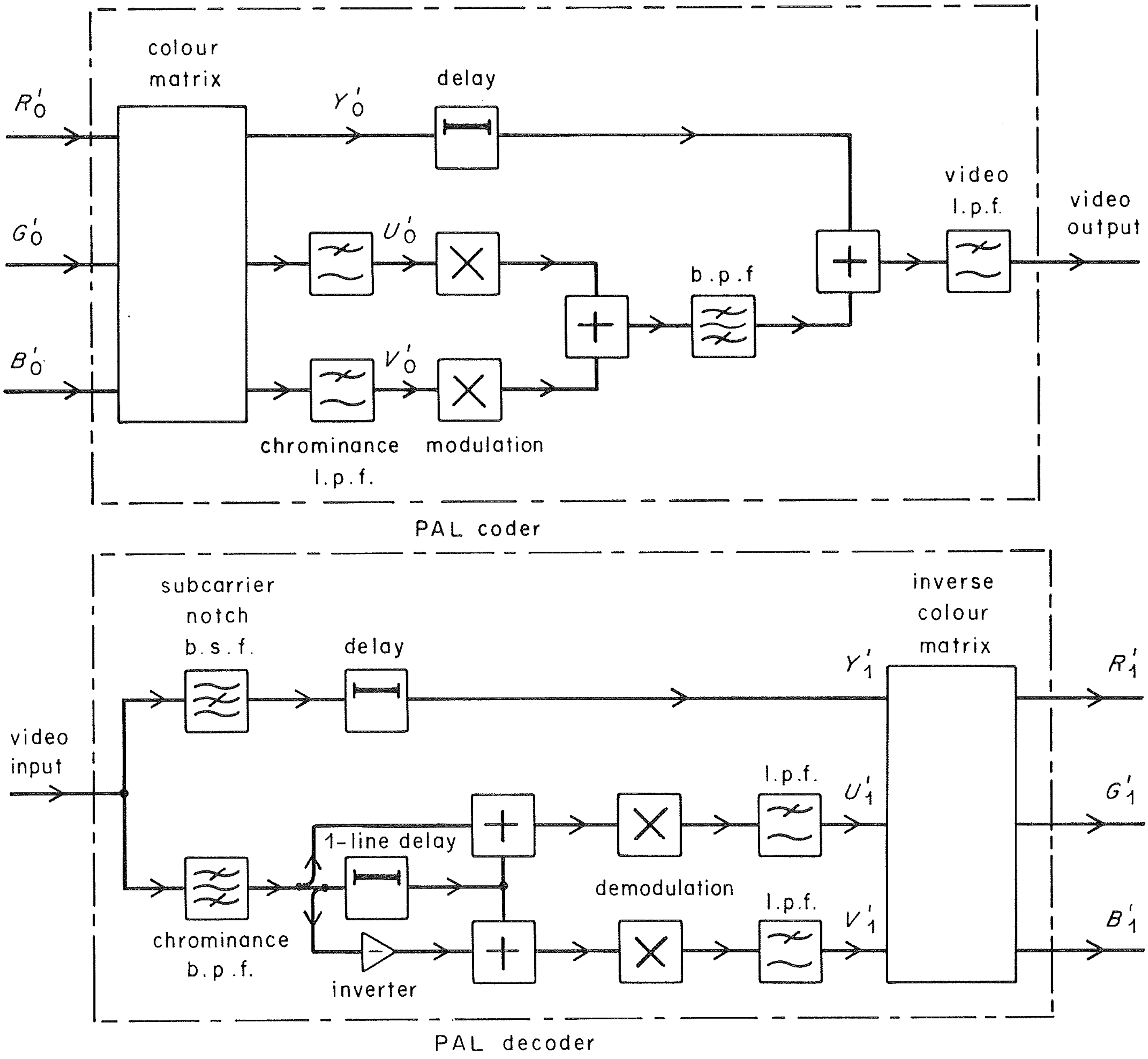


Fig. 7 - PAL codec filters

TABLE 4

Frequency characteristics of the chrominance channels in the PAL codec

Frequency (MHz)	Attenuation in dB				
	Coder U, V low-pass filters	Average of U, V low-pass*+ chroma band-pass filters	Decoder Average of U, V band-pass + low-pass filters	TOTAL	MEASURED TOTAL
0·5	0·3 ± 0·3	2·0 ± 1·0	1·0 ± 0·4	3·0 ± 1·4	2·0 ± 0·3
0·9	1·9 ± 0·3	4·0 ± 1·0	2·3 ± 0·4	6·3 ± 1·4	6·0 ± 0·3
1·6	6 ± 1	12 ± 2	7·5 ± 1·0	20 ± 3	18 ± 2
2·1	15 ± 2	20 ± 2	13·0 ± 1·0	33 ± 2	35 ± 2

* Measured using a sinusoid and spectrum analyser

decoder A which was used in the present work).

The overall chrominance amplitude-frequency characteristic of the codec (see Fig. 1) is −3 dB at 640 kHz and −20 dB at 1·6 MHz, i.e. a fairly gentle roll-off. It should be noted that the measured response above about 2·0 MHz is invalidated by the presence of cross-colour and chrominance to luminance cross-talk signals.

The step response of the codec was measured by applying a 100% vertical colour-bar test signal to its input and monitoring the decoded U', V' signals with an oscilloscope. The green to magenta transition in the colour-bar waveform was used in the measurements and the step response of the codec with and without a 1·5 MHz transmission filter added are shown in Fig. 9. This Figure shows that for the PAL codec alone there is a 3% overshoot on a step function and subsequent ringing is less than 0·5% in amplitude.

The characteristics of various signal paths in the PAL codec are included in the results above, and in general

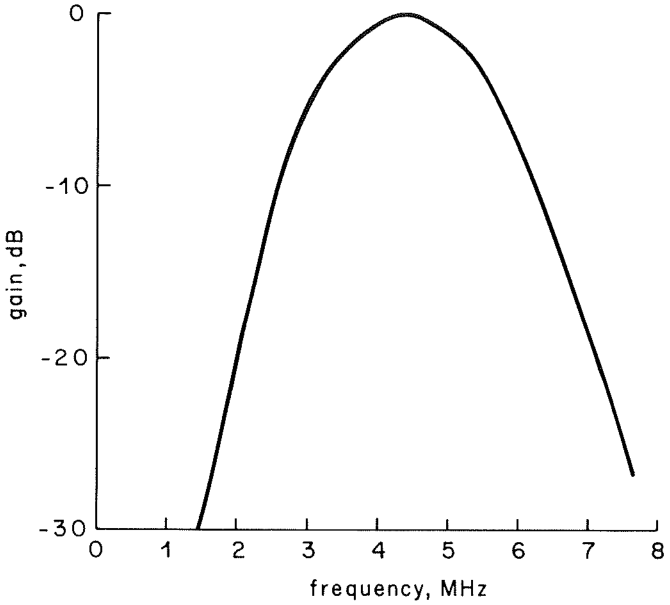
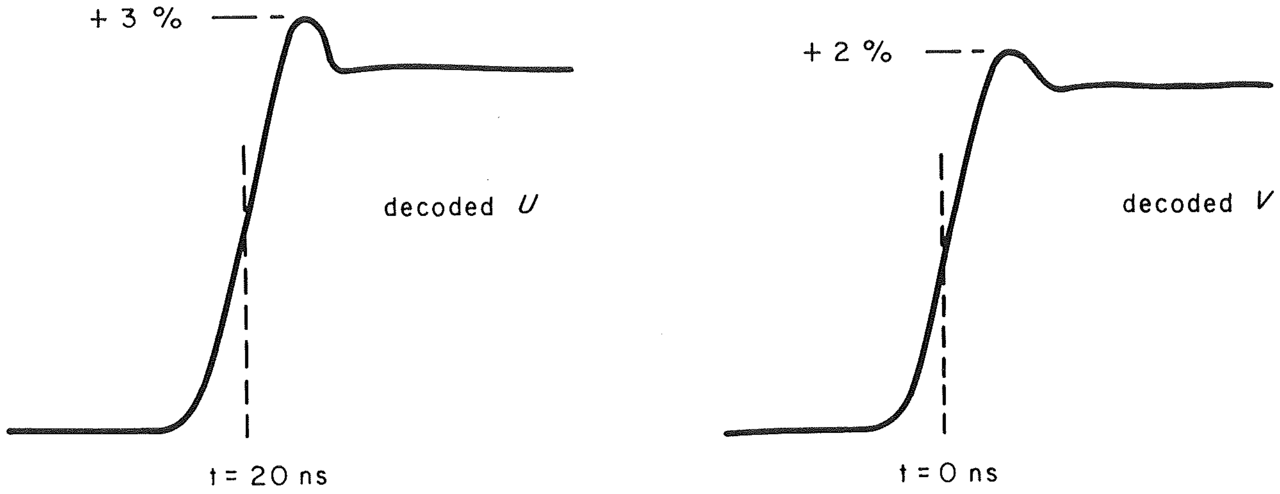
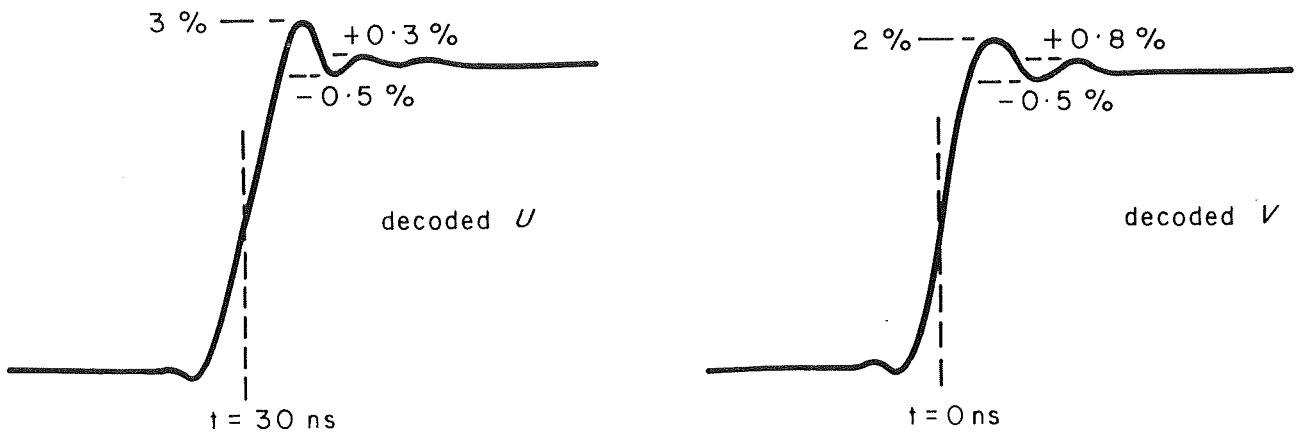


Fig. 8 - Amplitude frequency characteristic of the decoder chrominance band-pass plus U' or V' low-pass filters



PAL codec



PAL codec + 1·5 MHz transmission filters

Fig. 9 - Step response of chrominance channels

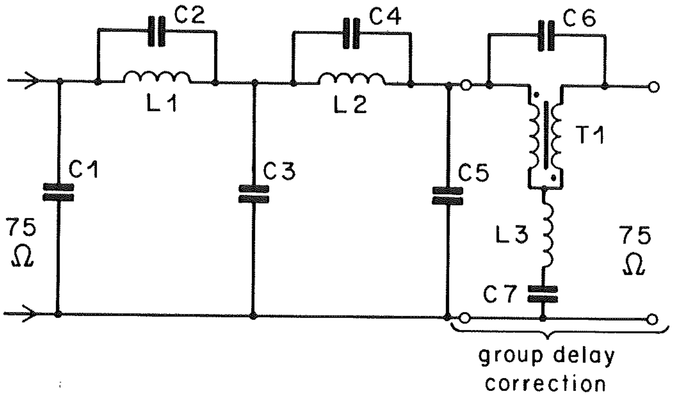
(a) PAL codec
(b) PAL codec plus transmission filters

It was found that the measured bandwidths are narrower than specified.[4] For instance the measured amplitude-frequency characteristic of the chrominance low-pass filters in the coder is −2 dB at 900 kHz, cf. 1·2 MHz in Ref. 2, and −20 dB at 2·3 MHz, cf. 3 MHz in Ref. 2.

8. APPENDIX 2

Details of Experimental U', V' Transmission Filters

Fig. 10 shows the circuit diagram and component values for filters 1, 2 and 3. As these filters are each second-order elliptic they will each have geometrically similar transient responses; accordingly only one set of step responses (with and without group-delay correction) is shown in Fig. 10. Fig. 11 gives the circuit diagram and impulse response for filter 4 (raised cosine).



	Filter	1(1·5MHz)	2(1·1MHz)	3(700kHz)
pF	C1	1530	1989	3108
	C2 *	114	148	232
	C3	2730	3550	5550
	C4 *	334	434	678
	C5	1350	1755	2742
	C6 *	604	785	1227
	C7	6700	8710	1361
μH	L1	11·95	15·54	24·27
	L2	10·45	13·59	21·23
	L3	3·04	3·95	6·18
	T1	37·6	48·9	76·4

* The stray capacitance of the inductors should be subtracted from these values

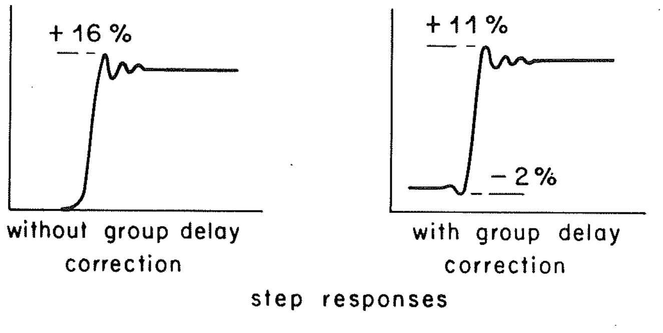
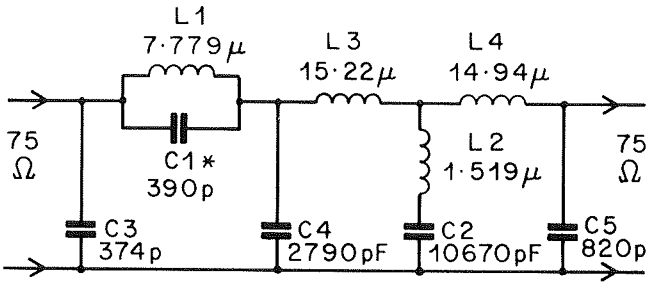


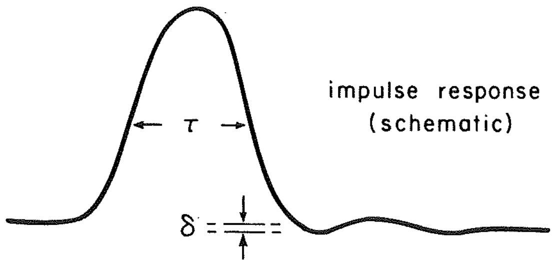
Fig. 10 - Circuits and step responses of filters 1, 2 and 3



All capacitances in pF's

All inductances in μF's

∗ The stray capacitance of the inductor should be subtracted



τ = 830 ns

overshoot δ = 0·8 %

Fig. 11 - Circuit and impulse response of filter 4

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